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Status of the Node 3 Regenerative ECLSS Water Recovery and Oxygen Generation Systems

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ABSTRACT

NASA's Marshall Space Flight Center is providing three racks containing regenerative water recovery and oxygen generation systems (WRS and OGS) for flight on the *International Space Station's (ISS)* Node 3 element. The major assemblies included in these racks are the Water Processor Assembly (WPA), Urine Processor Assembly (UPA), Oxygen Generation Assembly (OGA), and the Power Supply Module (PSM) supporting the OGA. The WPA and OGA are provided by Hamilton Sundstrand Space Systems International (HSSSI), while the UPA and PSM are being designed and manufactured in-house by MSFC. The assemblies are currently in the manufacturing and test phase and are to be completed and integrated into flight racks this year. This paper gives an overview of the technologies and system designs, technical challenges encountered and solved, and the current status.

INTRODUCTION

The ISS Node 3 element is being manufactured and integrated by Alenia Spazio, under contract through the Italian Space Agency (ASI), with oversight by NASA's Marshall Space Flight Center.

The Node 3 architecture was designed to accommodate the U.S. regenerative ECLSS systems to enable the ISS to grow its crew size from three to six or seven. These regenerative systems include the Water Recovery System, comprised of the Urine Processor Assembly and Water Processor Assembly, and the Oxygen Generation System. The Oxygen Generation System includes the Oxygen Generation Assembly, the Power Supply Module that supports the OGA, and scars to accommodate the later addition of a Carbon Dioxide Reduction Assembly (CRA).

A schematic of the ECLSS for Node 3 is shown in Figure 1. In addition to the three Regenerative ECLSS racks, Node 3 will contain the second Atmosphere Revitalization System (ARS) rack, redundant to the ARS rack in the U.S. Lab, a third redundant Pressure Control Assembly (PCA), a Common Cabin Air Assembly, and other ancillary ECLSS equipment. For a complete description of the Node 3 ECLSS, see reference 1.

The layout of the various assemblies in the three Regenerative ECLSS racks is shown in Figure 2. The WPA is packaged entirely in WRS rack #1 and partially in WRS rack #2, linked by process water lines running between the two racks. The remaining portion of WRS rack #2 houses the UPA. The OGS rack, or Rack #3, contains the OGA, PSM, and a scar for the Carbon Dioxide Reduction Assembly (CRA) consisting of fluid and electrical interfaces and a carbon dioxide accumulator packaged in the bottom of the rack. ORU's designated with an "H" in the diagram are provided by Hamilton Sundstrand Space Systems Incorporated (HSSSI); while ORU's designated with an "M" are provided by NASA Marshall Space Flight Center. HSSSI is integrating their WPA and OGA hardware into flight racks 1 and 3, and MSFC is integrating rack 2 and completing rack 3 integration with the PSM and common hardware (avionics air assembly, smoke detector, rack power switch).

Due to limitations on Node 3 launch weight, only the OGS rack is currently planned to launch with Node 3. The WRS racks will be de-integrated from Node 3 following system testing, and will be launched on a separate Multipurpose Logistics Module (MPLM) flight and installed into Node 3 on orbit. Current plans are to allow the regenerative systems to operate for an initial period prior to increasing crew size.

The following sections provide a description of the WRS and OGS, give current status, and describe issues and lessons learned during the past year. For the prior years' status, see references 2 and 3.

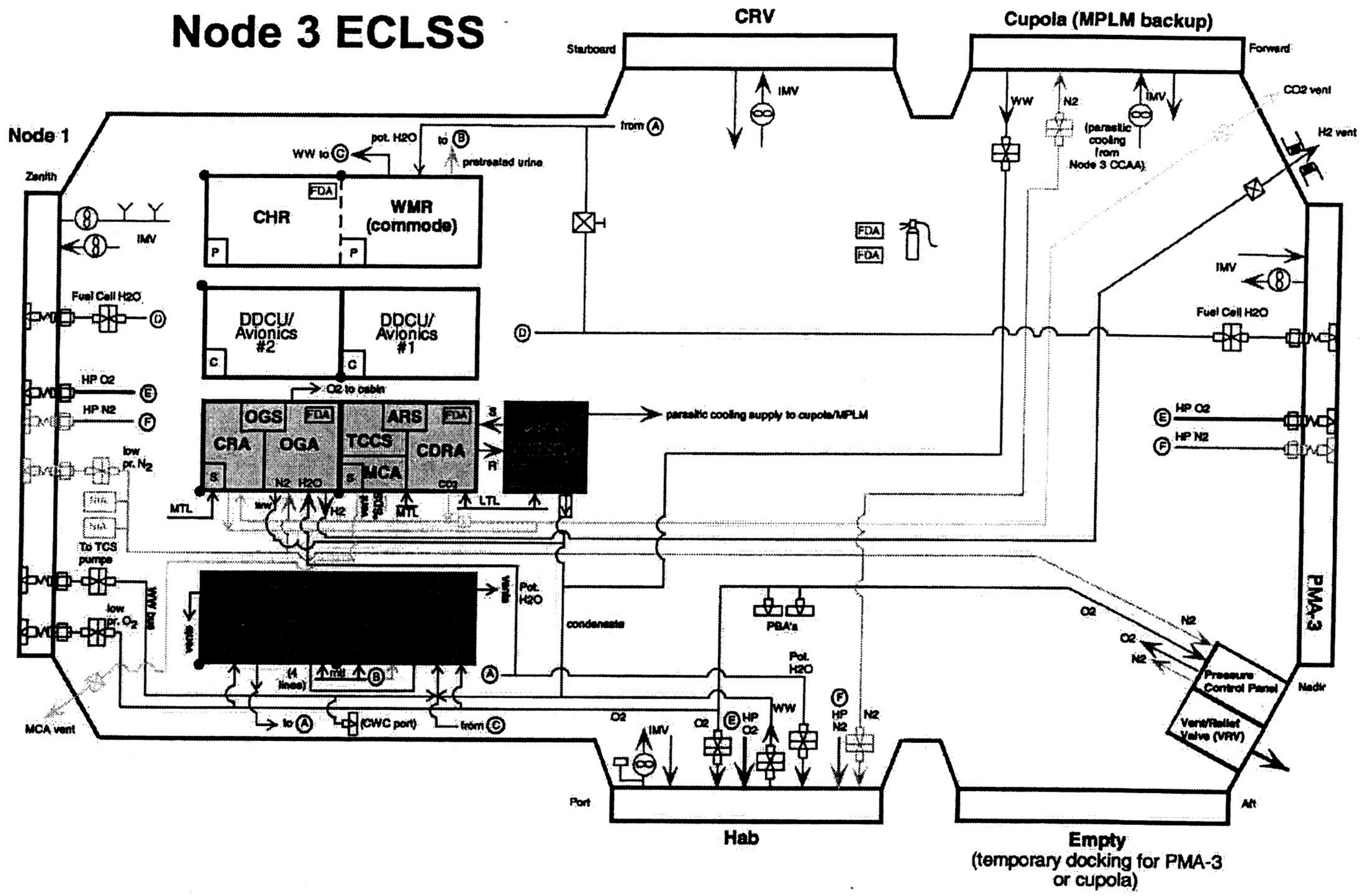

Figure 1. Node 3 Environmental Control and Life Support System Schematic

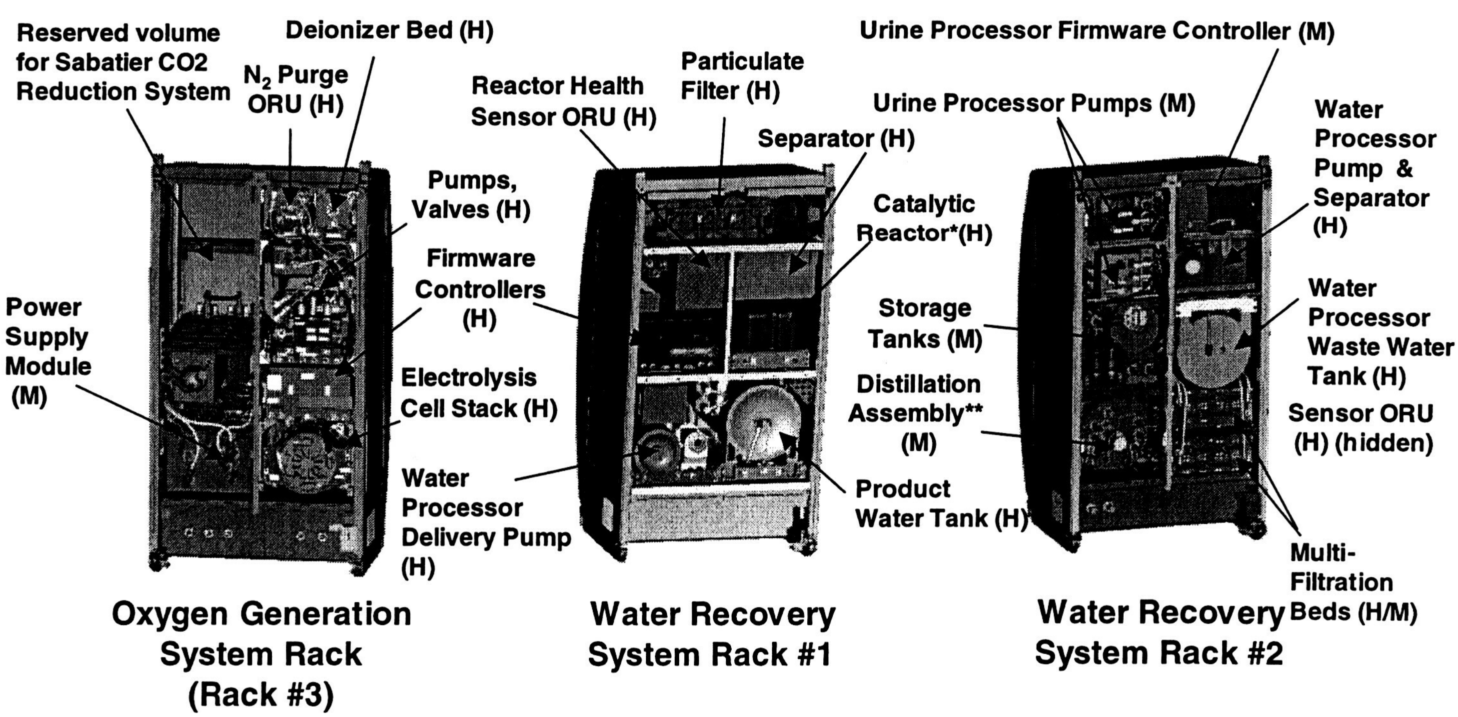

Figure 2. Regenerative Environmental Control and Life Support System Racks

WATER RECOVERY SYSTEM

WATER PROCESSOR ASSEMBLY OVERVIEW – A simplified schematic of the WPA is shown in Figure 3. Wastewater delivered to the WPA via the station wastewater bus is temporarily stored in the Wastewater ORU. Gas is removed from the wastewater by the Mostly Liquid Separator (MLS) (part of the Pump/Separator ORU), and passes through the Separator Filter ORU where odor-causing contaminants are removed before returning to the cabin. Next, the water is pumped through the Particulate Filter ORU followed by two Multifiltration beds where non-volatile organic and inorganic contaminants are removed. There are two Multifiltration beds in series. Once breakthrough of the first bed is detected, the second bed is relocated into the first bed position, and a new second bed is installed. The Sensor ORU (not shown) helps to determine when the first MF bed is saturated. Following filtration, the process water stream enters the Catalytic Reactor ORU, where low molecular weight organics not removed by the filtration process are oxidized. A regenerative heat exchanger recovers heat from the catalytic reactor to make this process more efficient. The Gas/Liquid Separator ORU removes oxygen from the process water and returns it to the cabin. The Reactor Health Sensor ORU monitors the performance of the reactor to ensure it is not being overloaded. Finally, the Ion Exchange bed ORU removes the products of oxidation before the water is stored in the product water tank prior to delivery to the station potable water bus. The Water Storage ORU is the main storage tank for the potable water, while the Water Delivery ORU contains a pump and small accumulator tank to deliver potable water "on demand" to users. The WPA is controlled by a firmware controller, which interfaces to the Node 3 Tier II controller.

The WPA is designed to nominally process 50.8 kg/day (112 lbs/day) of wastewater including humidity condensate, urine distillate, waste hygiene, EVA wastewater, and CO_2 reduction product water (Sabatier scar). It is capable of processing a maximum of 100 kg (221 lbs) of wastewater over a 16-hour period. Due to recent changes in expected wastewater loads, these requirements are currently being revised. This change is discussed further in the following section. The WPA operates in a batch processing mode, consuming 654 W when processing, and 380 W during standby (current projections). Product water must meet station potable water quality requirements as defined by the Space Station System Specification (reference 4). The WPA delivers product water at a flow rate of 226.8 kg/hr (500 lbs/hr).

The WPA's 14 Orbital Replacement Units (ORUs) are packaged into approximately 1.5 equipment racks. Expendable ORUs (Particulate Filter, Multifiltration Beds, Ion Exchange Bed) are packaged for easy removal by the crew through the front of the rack.

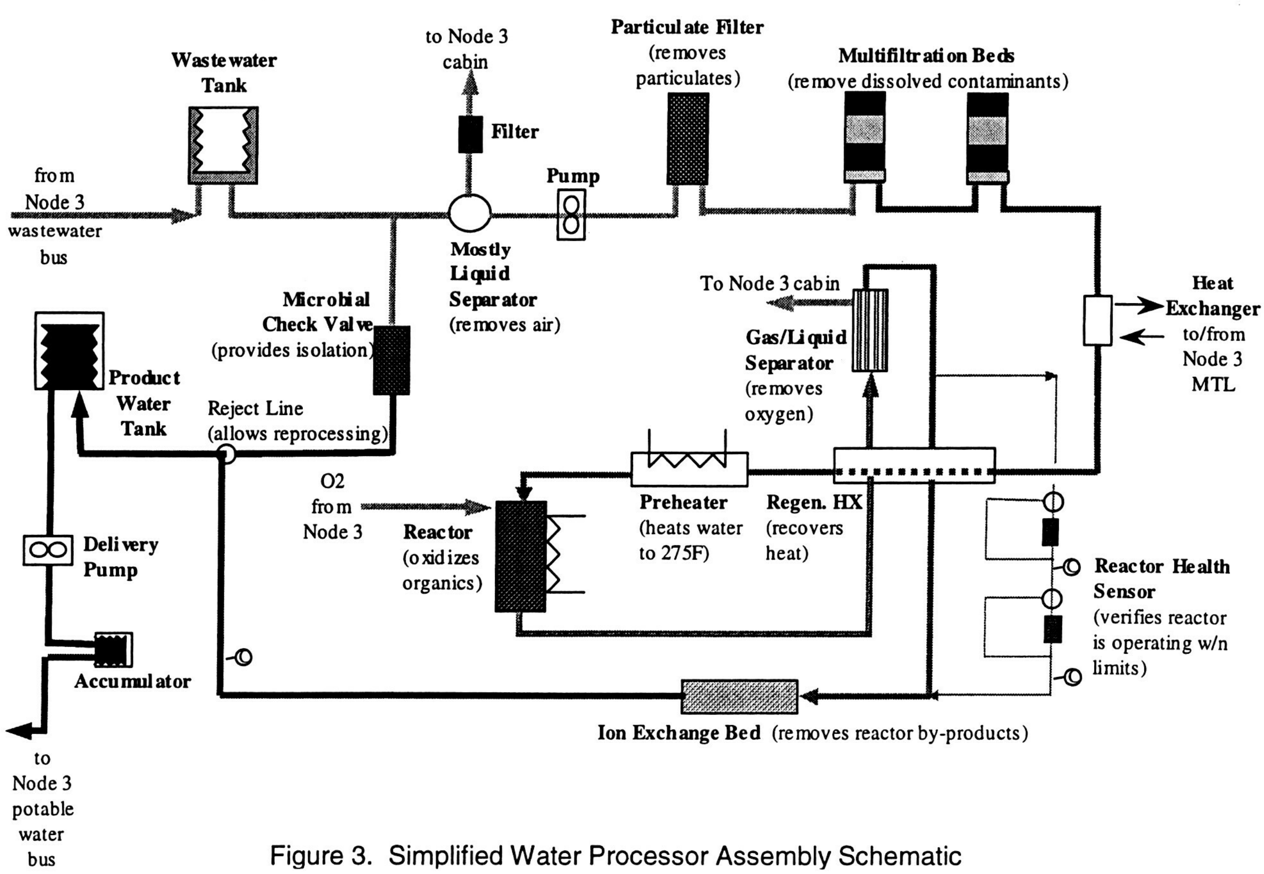

Figure 3. Simplified Water Processor Assembly Schematic

WATER PROCESSOR ASSEMBLY CURRENT STATUS AND CHALLENGES – Table 1 gives a current status of manufacturing and testing for the WPA. Currently, 5 of the WPA ORUs are complete through protoflight testing, and 11 complete through manufacturing and currently in test. The remaining ORUs are scheduled to be complete by mid-July, 2003.

Table 1. Water Processor Assembly ORU Status

ORU	Manufacturing Status	Acceptance Testing Status
Wastewater	In final assembly; reworked quantity sensor potentiometer	ECD July, '03
Pump/ Separator	Complete, but reworking for valve, & MLS failures. Pump to be replaced.	ECD July, '03
Separator Filter	Complete	Complete
Particulate Filter	Complete	Complete
Sensor	Complete	Complete
Multifiltration Bed	Planned for '04 due to shelf life	Planned for '04 due to shelf life (mass simulator to be used for WPA system testing
Catalytic Reactor	In final assembly	ECD July '03
Reactor Health Sensor	Complete	In test; ECD June '03
Ion Exchange Bed	Complete	Complete
Microbial Check Valve	Complete	Complete
Water Storage	Complete	In test; ECD June '03
Water Delivery	Complete; Pump to be replaced.	In test; ECD June '03
Gas Liquid Separator	Complete, but reworking for vent valve failure during test	ECD June '03
Controller	Complete	ECD May '03

As is common with any flight hardware program, there have been challenges encountered as the WPA has progressed through the manufacturing and test phase this past year. After successfully completing development cycle testing, the wastewater and delivery pumps experienced failures during qualification cycle testing. Troubleshooting revealed that the pump was unable to withstand the thrust load imparted by the motor. This problem had not surfaced during development, as the pump had not been tested under flight-like thrust load conditions. To resolve this issue, the pump is currently undergoing a redesign. The fix involves remachining the pump shaft to eliminate a shoulder on the shaft that was transmitting axial thrust loads into the pump's driven gear (made of zirconia) and causing it to ride and wear against a harder alumina oxide surface on the pump housing. The key that attaches the gear to the shaft is also being redesigned to allow the driven gear to float axially on the shaft. The redesign will be incorporated into the spare pumps, which will be exchanged with the current flight pumps following completion of WPA system level testing.

The conductivity sensor design used in the Reactor Health Sensor was determined through engineering analysis to be potentially sensitive to two-phase flow in microgravity. This sensitivity was confirmed through tests run on a development sensor flown on the NASA KC-135, which showed a measurement offset from 0-50%. To correct this problem, a gas-tolerant sensor has been designed and successfully tested. This sensor will replace the existing sensor in the WPA prior to flight. Reference 5 provides complete information on this issue, the test data, and resolution.

Another issue discovered and resolved this past year related to the Mostly Liquid Separator. Troubleshooting of the MLS, which had seized during in-process testing, revealed corrosion on its shaft. Materials analysis identified a small percentage of iron in the coating material to be the cause of the corrosion. The shaft was stripped and replaced with a chrome coating, and the MLS was successfully returned to test.

Issues associated with the water tank quantity sensor potentiometer design surfaced following vibration testing of the Water Storage ORU when one of the two redundant sensors failed to read correctly. The failure was traced to a setscrew, which had backed out during the test. A pin was added as a locking feature to the potentiometer design to prevent reoccurrence. Following rework of this problem, the ORU was returned to test. Subsequent to the rework of the Wastewater ORU, which contained an identical quantity sensor design, two additional problems with the potentiometer were discovered. The metal sensor clip had broken during linearity testing of the tank, and the nylon coating on the cable had begun to fray. The clip is being replaced with one that is more structurally robust, while the nylon coating has been removed.

To date, there have been two solenoid valve failures occur during WPA ORU testing. The vent valve on the Gas Liquid Separator ORU was found to be leaking during test. Troubleshooting and valve teardown revealed a particle on the sealing surface to be the cause of the leakage. The particle size was within the cleaning specification for the valve, which has led to concerns relative to the robustness of the WPA valve designs in the expected environment. The addition of particulate screens into the system and tighter cleaning procedures are being considered to provide an additional measures of protection. Second, a solenoid valve in the Mostly Liquid Separator (MLS) failed to open during testing. The problem was a combination of lack of sufficient solenoid force and adhesion of the o-ring seal to the metal sealing surface. The valve has been reworked to correct these problems and is currently being reassembled.

The pH adjuster portion of the Reactor Health Sensor ORU consists of a packed bed containing Magnesium Oxide (MgO). During a disinfection procedure, it was discovered that hydration of the MgO to Magnesium Hydroxide causes the resin to swell and increase bed pressure drop. Tests are currently being conducted to fully understand this effect and account for it in bed packing procedures.

WPA software has completed formal testing and is ready to support system level testing planned for July through September 2003. A Functional Configuration Audit/Physical Configuration Audit (FCA/PCA) is planned for October 2003.

This past year, interface changes resulting from actual on-orbit water usage data and changes in architecture configuration were assessed for impacts to the WPA requirements. These included: changes to expected ISS on-orbit water usage; deletion of the shower and modification to hygiene water usage; cancellation of funding for the Node 3 W&HC and direction to Regen ECLSS to process Russian pretreated urine; and updated requirements for payloads and life science experiments. These changes resulted in a reduction in wastewater load of 22.7 kg/day (50 lbs/day), and a higher expected concentration of volatile organics in the wastewater than previously specified. MSFC and HSSSI verified that the new ratio of ionic contaminants to organics is still within the MF bed design. Although the higher Total Organic Carbon (TOC) load to the reactor now exceeds its design capacity, an increased ISS oxygen supply pressure to the interface (based on actual on-orbit data) results in more oxygen flow. Because there was insufficient delta between the nominal load on the reactor (~65 ppm TOC) and the load that would overwhelm the reactor, a recent decision was made to reduce the WPA flowrate from 7.2 kg/hr (16 lb/hr) to 5.9 kg/hr (13 lb/hr). MSFC is planning to conduct testing to establish the reactor performance with the higher organic load and oxygen flow, and lower flowrate.

Figure 4 shows pictures of some WPA completed hardware.

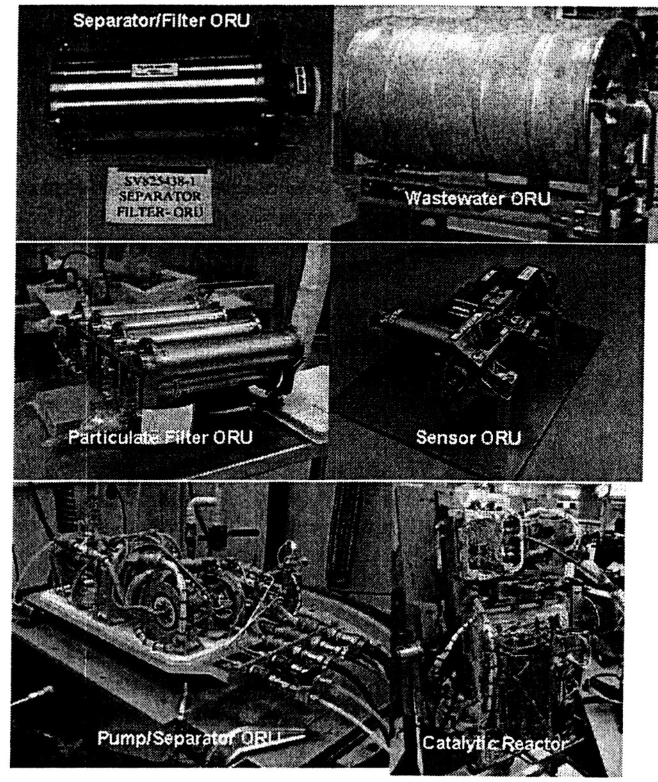

Figure 4. Water Processor Assembly Flight Hardware

URINE PROCESSOR ASSEMBLY OVERVIEW – A simplified schematic of the UPA is shown in Figure 5. Urine is delivered to the UPA either from the Node 3 Waste and Hygiene Compartment (currently scarred only) or it can be supplied via manual transfer from the Russian EDV. The urine is temporarily stored in the Wastewater Storage Tank Assembly (WSTA) until it reaches a setpoint to begin processing. The Fluids Control and Pump Assembly (FCPA) is a four-tube peristaltic pump that moves urine into the Distillation Assembly (DA), concentrated waste from the DA into the Recycle Filter Tank Assembly (RFTA), and product water to the interface with the WPA. The DA is the heart of the UPA, and consists of a rotating centrifuge where the waste urine stream is evaporated at very low pressure and condensed on the opposite side of the surface thus conserving latent energy. A rotary lobe compressor provides the driving force for the evaporation and compression of water vapor. Waste brine resulting from the distillation process is stored in the RFTA. The Pressure Control and Pump Assembly (PCPA) is another four-tube peristaltic pump, which provides for the removal of non-condensable gases and non-condensed water vapor from the DA. These gases are pumped to the Separator Plumbing Assembly (SPA), which recovers and returns water from the purge gases to the product water stream. A Firmware Controller Assembly (FCA) provides the command control, excitation, monitoring, and data downlink for UPA sensors and effectors.

The UPA is designed to process a nominal load of 8.4 kg/day (18.6 lbs/day) of wastewater consisting of urine, flush water, and a small amount of waste from Environmental Health System water samples. At a maximum load, the UPA can process 13.6 kg (30 lbs) of wastewater over an 18-hour period per day. Like the WPA, it operates in a batch mode, consuming 424 W when processing, and 108 W during standby (current projections). Product water from the UPA must meet specification quality requirements for conductivity, pH, ammonia, particles, and total organic carbon. It must recover a minimum of 85% of the water content in the specified wastewater stream.

The UPA is packaged into 7 ORUs, which take up slightly more than half of the WRS Rack #2. The RFTA is the only expendable ORU, designed for a 30-day changeout.

URINE PROCESSOR ASSEMBLY CURRENT STATUS AND CHALLENGES – Table 2 gives the current status of UPA ORUs through manufacturing and test. Several ORUs are in final assembly, with final preparations for ORU testing in progress. The remaining ORUs are scheduled to be complete in September 2003. Figure 6 shows some photographs of completed UPA hardware.

A number of issues have been addressed during component and assembly manufacturing, and in UPA development testing this past year. Reference 6 focuses on the UPA system development issues in detail; however, some summary is presented here.

Several issues arose during UPA component welding. The first flight article RFTA failed several weld inspections before the process was improved to provide a reliable weld. The first weld showed an "enigma" which could not be explained by non-destructive evaluation experts as a crack or lack of fusion. After extensive analysis, a decision was made to remove the RFTA mid-ring and attempt the weld again. Subsequent attempts failed due to unacceptable weld porosity. Process improvements ultimately resulted in a successful weld, and the original "enigma" was likely due to a fit-up offset between the shell cylinder and mid-ring. The Distillation Assembly centrifuge tank also proved challenging due to its geometry and manual welding operation. Improvements in its welding process developed as part of the RFTA welding resulted in a successful weld.

Finally, the completed qual and flight WSTA bellows both exhibited leakage above internal vendor specifications. After additional leak testing and unsuccessful attempts to reduce leakage by reworking isolated areas, a decision has been made to remanufacture both bellows. Improvements in the cleaning/welding process, new fixturing to support the bellows in its expanded position, and tighter control on the raw material mill run used are being implemented for the remanufacture.

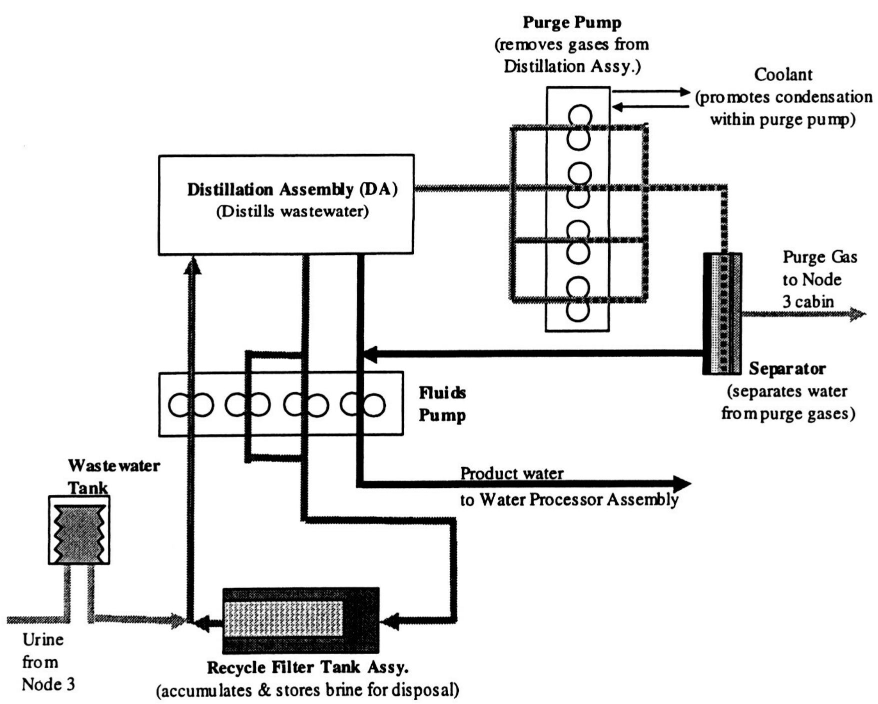

Figure 5. Urine Processor Assembly Simplified Schematic

Table 2. Urine Processor Assembly ORU Status

ORU	Manufacturing Status	Acceptance Testing Status
Wastewater Storage Tank Assembly	In assembly; new bellows being manufactured. ECD July 2003	ECD August 2003
Pressure Control & Pump Assembly	In final assembly following check valve rework; ECD June 2003.	ECD September 2003
Fluids Control & Pump Assembly	In final assembly following check valve rework; ECD August 2003	ECD September 2003
Distillation Assembly	Component machining complete; compressor testing underway. ECD September 2003	ECD September 2003
Separator Plumbing Assembly	In final assembly following check valve rework. ECD May 2003	ECD June 2003
Firmware Controller Assembly	Cards being integrated into Data and Power Module boxes. ECD July 2003	ECD September 2003

Assembly work on the SPA, PCPA, and FCPA experienced a setback when the relief and check valves contained in these ORUs had to be returned to the vendor due to workmanship and design issues that prevented them from functioning reliably. Following rework, the check valves still had difficulty meeting their specified cracking pressure following exposure to the maximum back pressure. A modification to the spring and poppet components of the check and relief valves corrected the operation of the relief valves. An additional adjustment to open up the tolerance of the check valve bore was required to eliminate the "stiction" of the o-ring after exposure to the maximum backpressure. The valves have been returned to MSFC, have been retested, and are being readied for integration into the ORUs.

Pressure sensors within the UPA, manufactured by two different vendors, were also delayed. One set of sensors had two issues that delayed their delivery. The sensors exhibited a negative drift that was eventually understood, corrected, and made acceptable. Second, the sensors were assembled with commercial grade parts rather than Grade B+, radiation-hardened parts. Additional screening tests on the sensors and parts were conducted to gain confidence in part/sensor quality to support a EEE parts waiver as opposed to rebuilding the sensors. The two EEE parts of the sensor that were questionable for radiation have since passed radiation testing.

The long term stability of the other pressure sensors used in the UPA was called into question when testing revealed that similar OGA sensors were experiencing drift problems. (See the following OGA discussion for details.) After determining that the UPA sensors were manufactured with Inconel produced in a vacuum remelt process, a decision was made to accept them as-is, but to periodically check calibration to determine if the drift would stabilize over time within an acceptable limit. In the meantime, a possible replacement sensor is being considered as risk mitigation.

A Program decision to delete the U.S. Waste and Hygiene Compartment (WHC) from the Node 3 baseline for funding reasons caused the Regen ECLSS Project to need to assess whether the UPA could process pretreated urine from the Russian urinal. Urine from the Russian segment is to be transferred manually via EDV's to the UPA interface. The Russian pretreat formula contains chromium trioxide/sulfuric acid as opposed to the U.S. sulfuric acid/oxone pretreatment. A combination of materials compatibility and performance tests conducted on the UPA development hardware indicates that the UPA can process the Russian pretreated urine without a design impact. A waiver will be required since the lower pH of the Russian pretreat results in a catastrophic fluid classification that would require triple seals not present in the current UPA design and would impact fracture critical requirements. The UPA design will still be capable of processing urine from the U.S. WHC if a decision is made it add it back to the Node 3 baseline.

Performance of the UPA in microgravity was addressed via KC-135 tests with a development distillation assembly and with the Vapor Compression Distillation Flight Experiment which flew on STS-107. Results from these experiments helped to confirm assumptions regarding behavior of fluids with in the UPA in microgravity and to finalize the heater design implementation to control condensate collection in the stationary bowl. For more details on these experiments, see reference 5.

Acoustic noise has been a concern, particularly with the UPA DA design. However, analytical predictions based on development test data indicate that the current design along with planned attenuation measures will meet the rack level NC-40 acoustic requirement.

UPA software was completed this past winter. The formal software testing was completed in March 2003, and is ready to support integrated controller and system testing. Ongoing activity to update software as a result of sensor/card testing and integrated testing with the controller is expected.